

Failure Analysis of CCD Image Sensors using SQUID and GMR Magnetic Current Imaging

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Abstract

■ During electrical testing of a Full Field CCD Image Sensor, electrical shorts were detected on three of six devices. These failures occurred after the parts were soldered to the PCB. Failure analysis was performed to determine the cause and locations of these failures on the devices. After removing the fiber optic faceplate, optical inspection was performed on the CCDs to understand its design and package layout. Optical inspection revealed that the device had a light shield ringing the CCD array. This structure complicated the failure analysis. Alternate methods of analysis were considered, including liquid crystal, light and thermal emission, LIVA, TIVA, 3CUID and MP. Of these, 3CUID and MP techniques were pursued for further analysis. The reasons for their selections are presented in the paper. Also, magnetoresistive current imaging technology is discussed and compared to 3CUID.

3CUID imaging was used to perform a scan of the current path under the light shield on the suspect side of the CCD. This imaging provided resolution up to 32 microns. Other MCI imaging parameters are provided in the paper. Using the 3CUID images, the location of the electrical short was isolated to two possible areas on the CCD. MP imaging was used for submicron resolution mapping of the suspect regions, further isolating the probable location of the failure. Parallel polishing was performed on the CCD to inspect this location. An anomaly was found at the location indicated by current imaging. Defect morphology suggested ECD as the cause of failure. FIB cross sectioning is being performed on the defect, to further evaluate the damaged area.

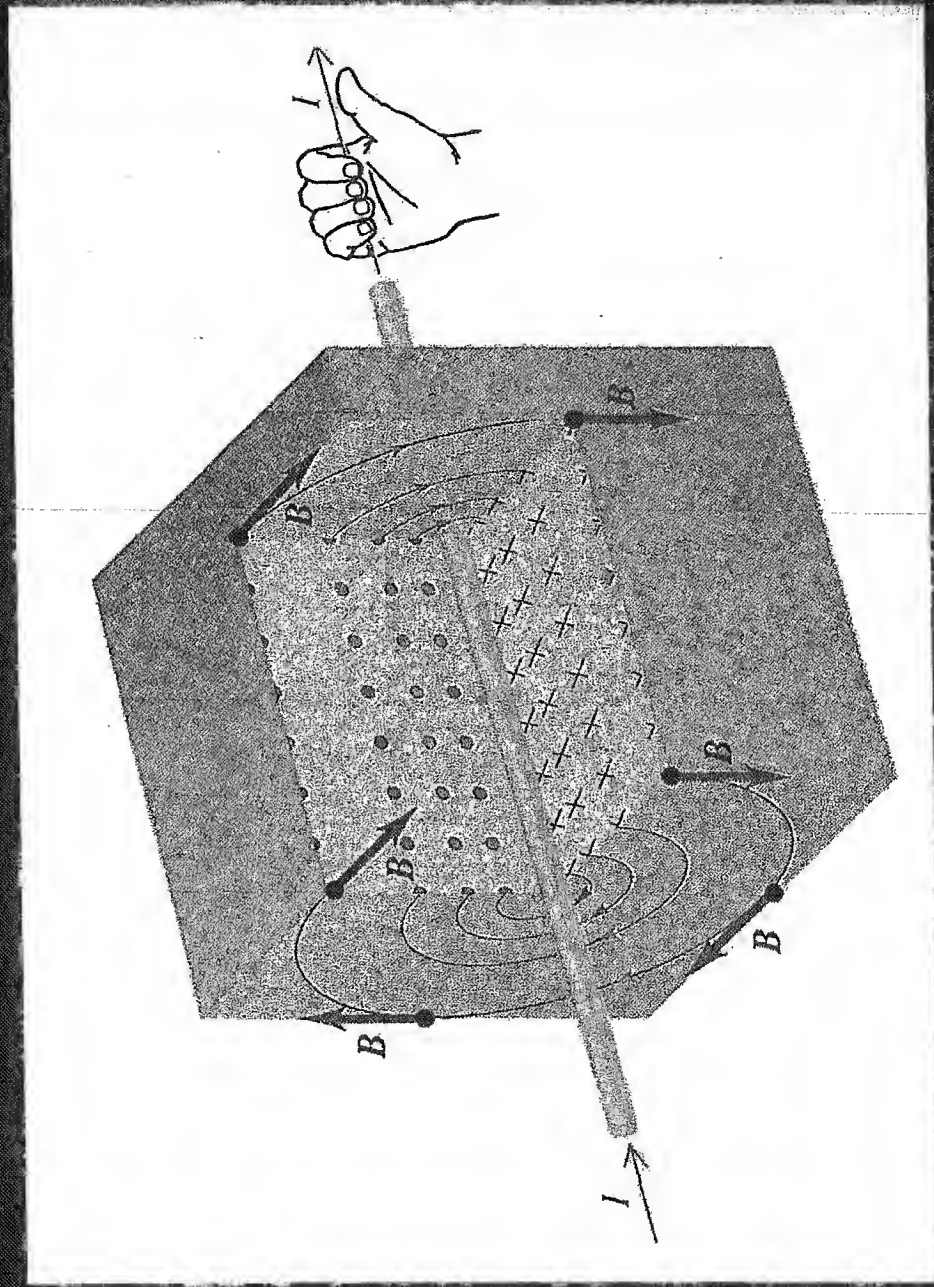
ECD protection technology and practices used at the test laboratory where these devices are being tested in the application mode is being reviewed to prevent ECD damage to a second set of CCD devices.

Some Fault Localization Techniques

- Liquid crystal
 - Relies on high resistance, Joule heating
 - Not strictly NDT
 - Spot size imprecise
 - Metallization spreads heat rapidly
- Thermal or photoemission (HgCdTe or InSb)
 - Photons require transparent medium
- TIVA or LIVA
 - Photons require transparent medium
 - Hindered by multi-level metallization stack

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Magnetic Current Imaging



Magnetic Current Imaging

■ Advantages

- Low resistance ideal
- Shows current path
- Transparent: aluminum metallization/ceramic
- NDT
- Sub-micron resolution

■ Disadvantages

- Distance sensitive
- Shows current path, not defect location

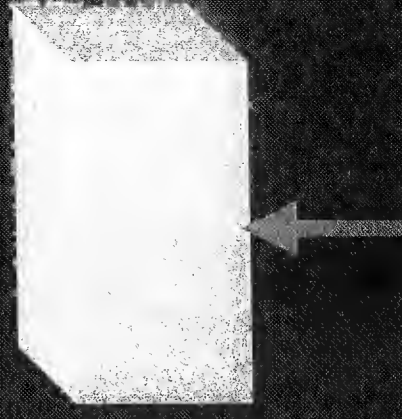
SQUID Sensor

- Superconducting quantum interference device
 - High-temperature superconductor ($\text{YBa}_2\text{Cu}_3\text{O}_7$) mounted on SrTiO_3 bi-crystal substrate
 - Sample at room temperature, but sensor requires low temperature, $T < 90\text{K}$
 - Sensitive to 20 pT ($1/2,000,000$ of Earth's magnetic field)
 - Detect 500nA at 400 microns range
 - Minimum standoff > 100 microns
 - Resolution: 30 microns



GMR Sensor

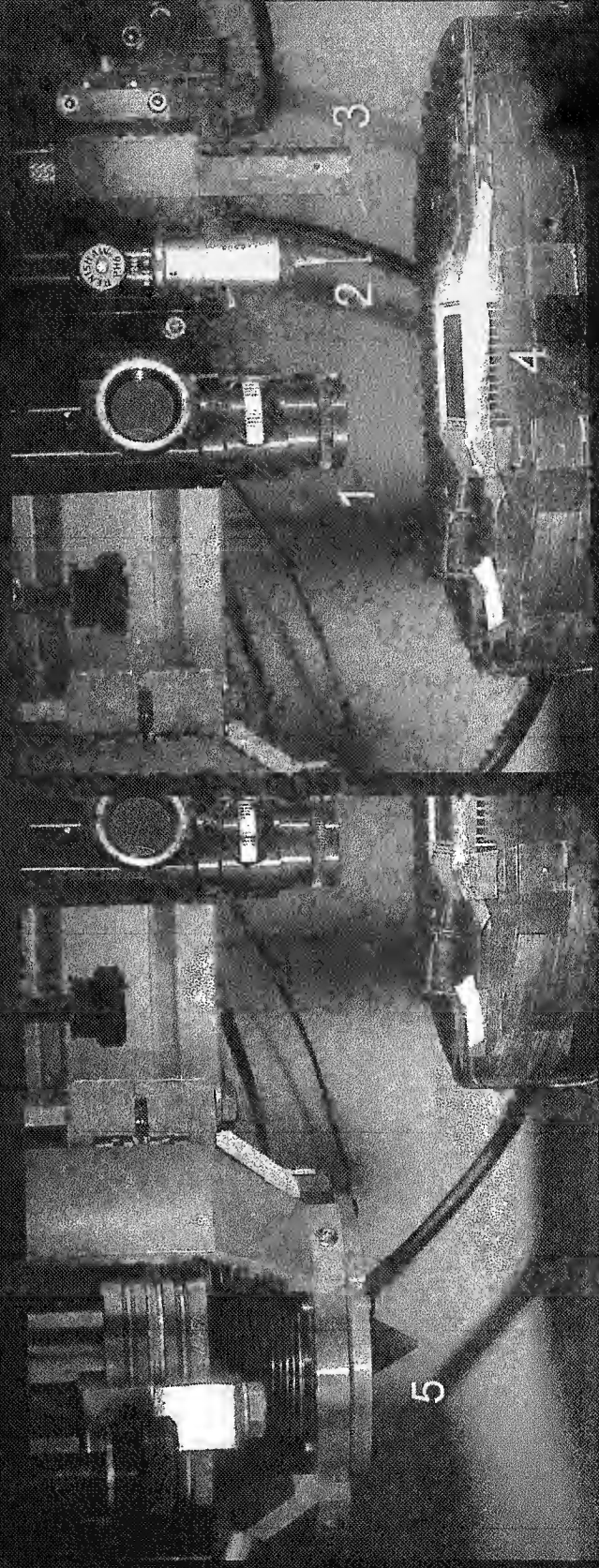
- Giant magneto-resistive sensor
 - NiFe or CoFe layers sandwich thin non-magnetic conductor
 - One magnet fixed, the other variable
 - Resistance of NM conductor changes with electron spin orientation, due to changes in external magnetic field
 - Minimum stand-off distance
 - Footprint ~ 1.0 mm



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View of MCI Test Chamber

- MCI probe fixed, mounted specimen moves
- Time: ~ 15 to 45 minutes



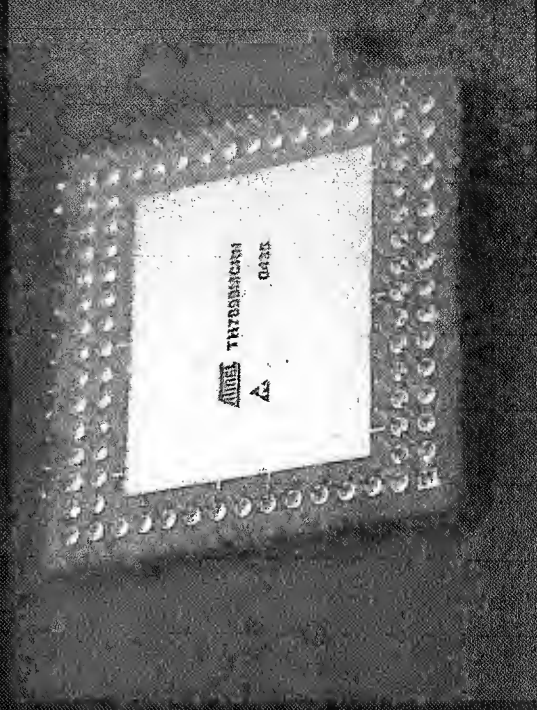
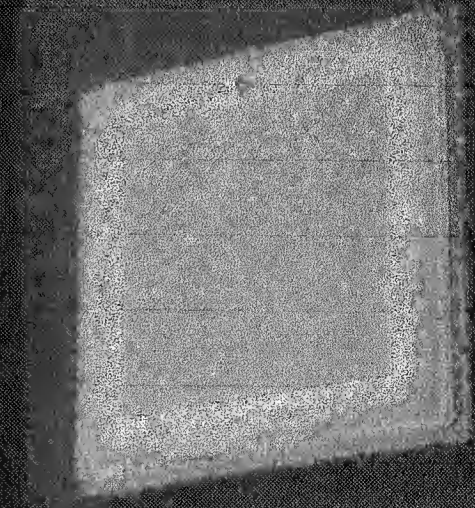
Background of Failure

- Satellite with four cameras
 - Purpose: study noctilucent clouds in mesosphere, 50 miles over polar regions each summer. Some evidence that brightness and frequency of noctilucent clouds has been increasing.
 - Satellite launch in fall 2006 into a polar orbit approximately 370 miles above Earth
 - Two of three cameras built with university partner
 - Two CCD failures threaten mission

TH7899M CCD Device

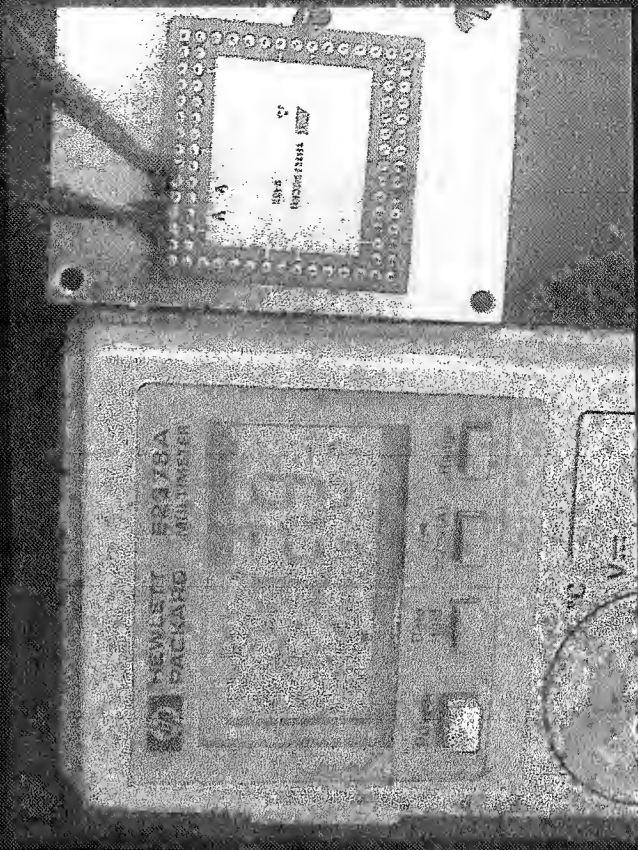
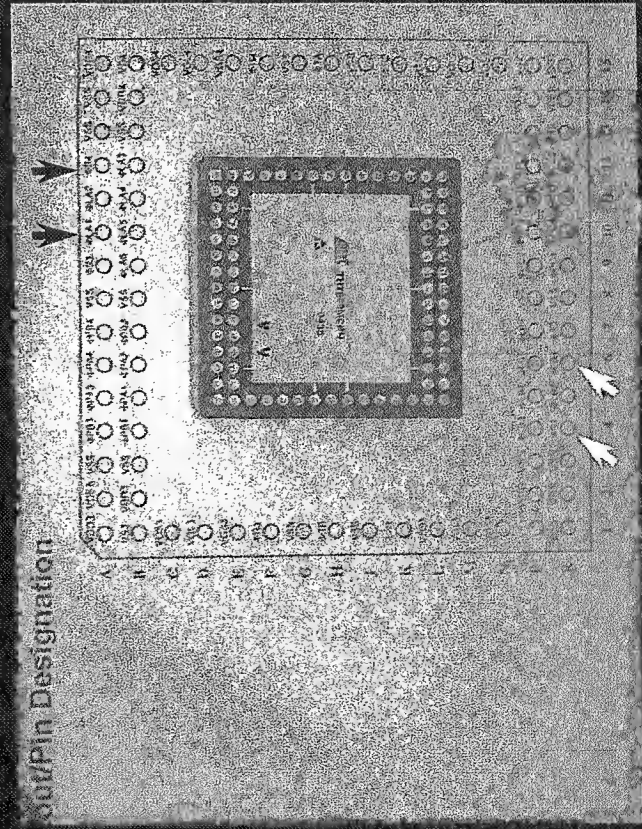
■ CCD devices

- Instrument grade CCD, 14 μ m square pixels
- Fiber optic faceplate covers array
- M2 aluminum light shield over periphery
- Manufacturer: device ESD sensitive to 20V



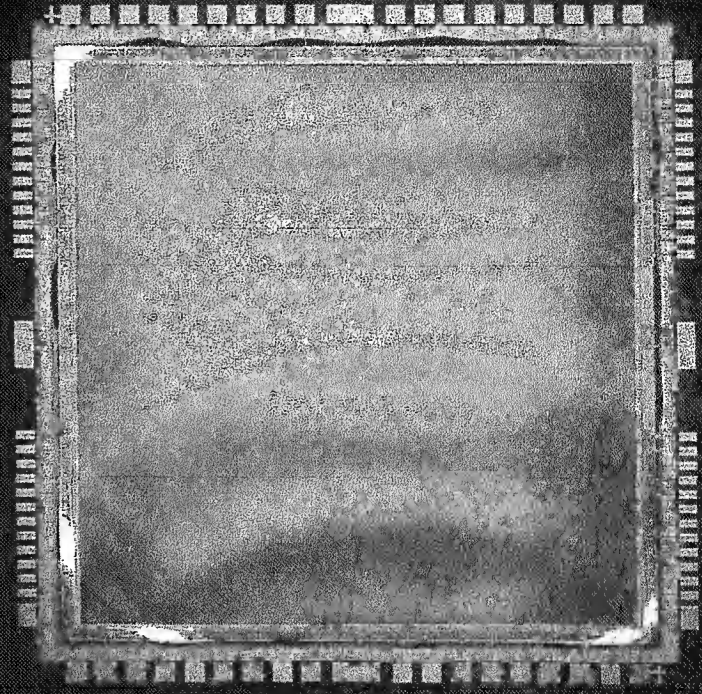
CCD Failures (SN06 and SN09)

- Ohmic shorts
- Between similar pins (SWA/B to LA/B1)
- Resistance: $E2\Omega < R < E3\Omega$



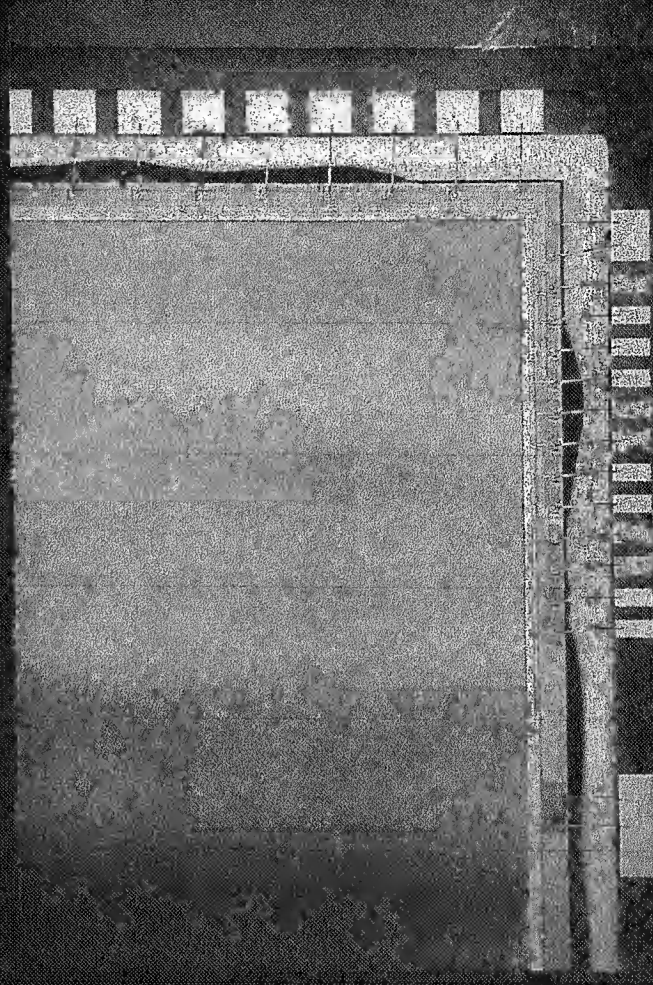
Initial Deprocessing

- Faceplate removed with solvent
- Glue removed by razor/O₂ plasma
- Aluminum light shield over periphery



Initial Deprocessing

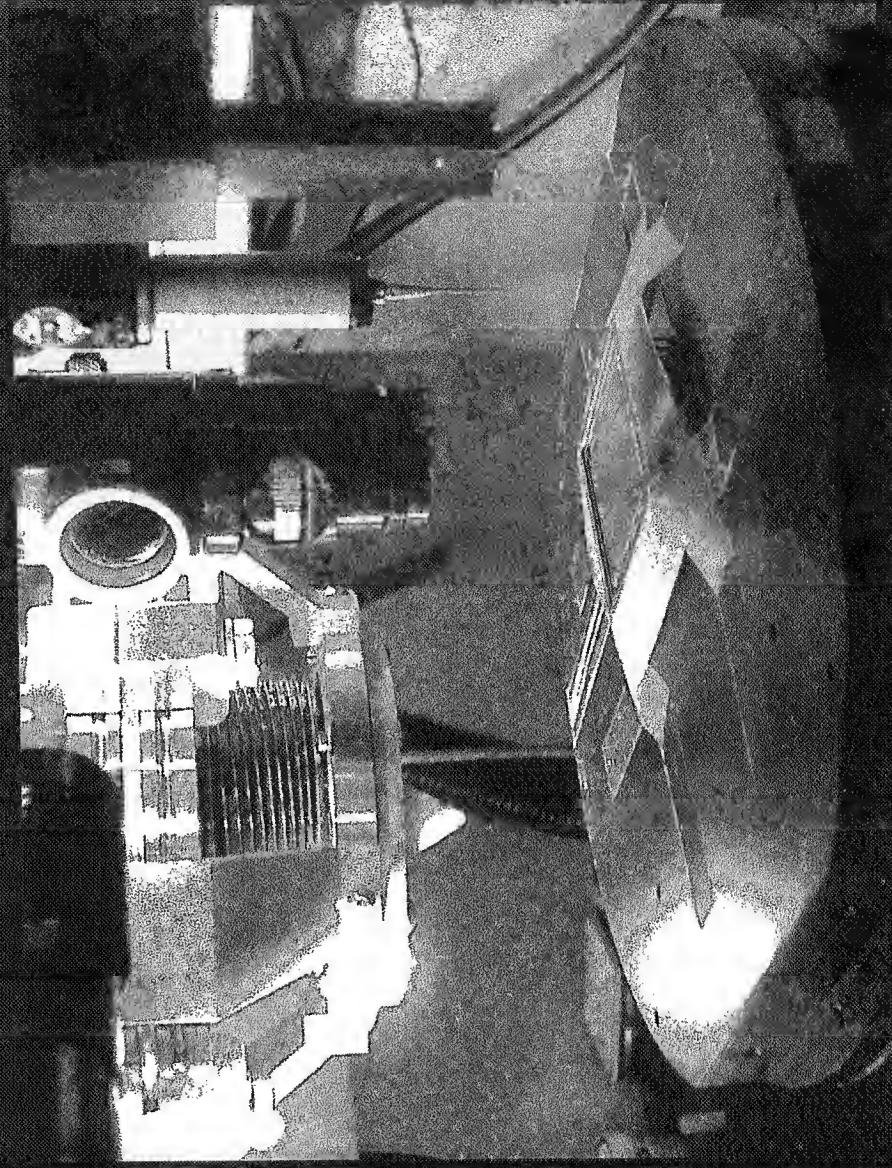
- Faceplate removed with solvent
- Glue removed by razor/O₂ plasma
- Aluminum light shield noted



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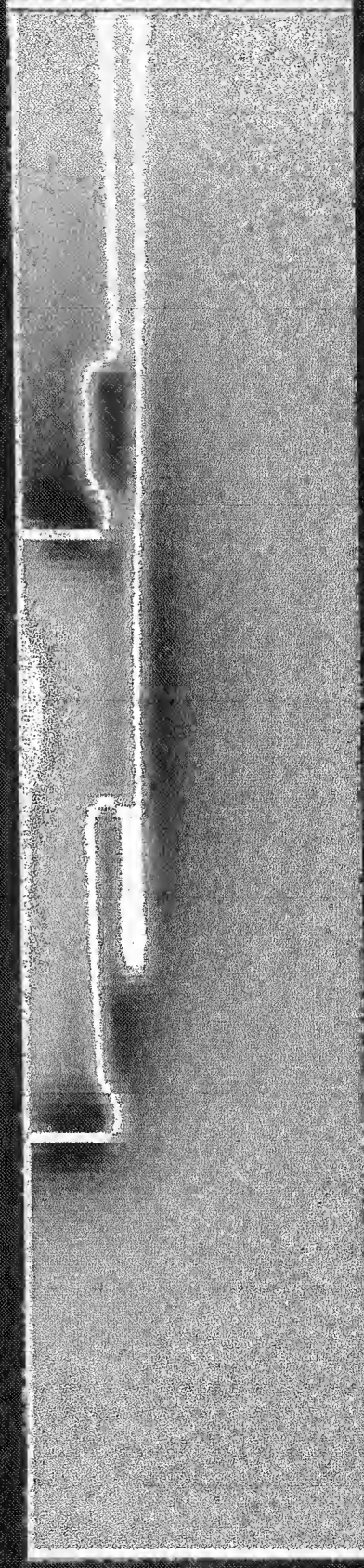
SQUID Set-up

- Probe corners and level device
- Scan plane
50 to 250 μm
- 9.557 kHz
- 1.0 mA



Magnetic Field Map

- Detects vertical component of B-field
- Fourier transform into Frequency Space
- Operator adjustments reduce noise
- Fourier back-transform into map



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SQUID Color Vector Plot

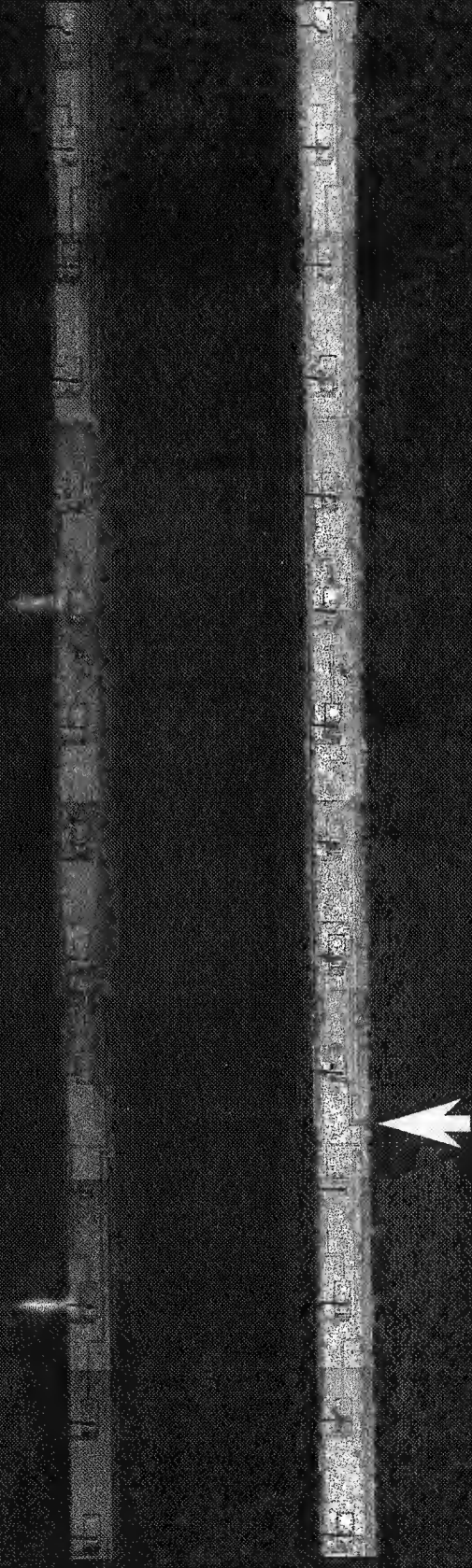
- Color shows direction of current flow
- Does not show current density



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SQUID Current Map

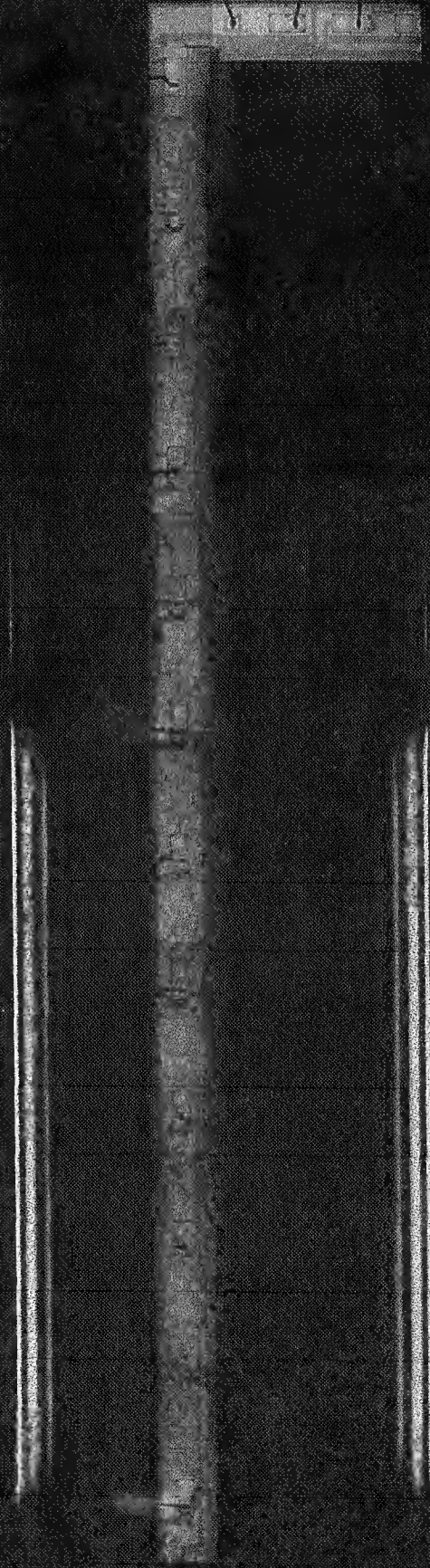
- Overlay: current map and optical image
- Scan plane at 50 microns
- Ceramic package blocks scan at CCD corner



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SQUID Current Map

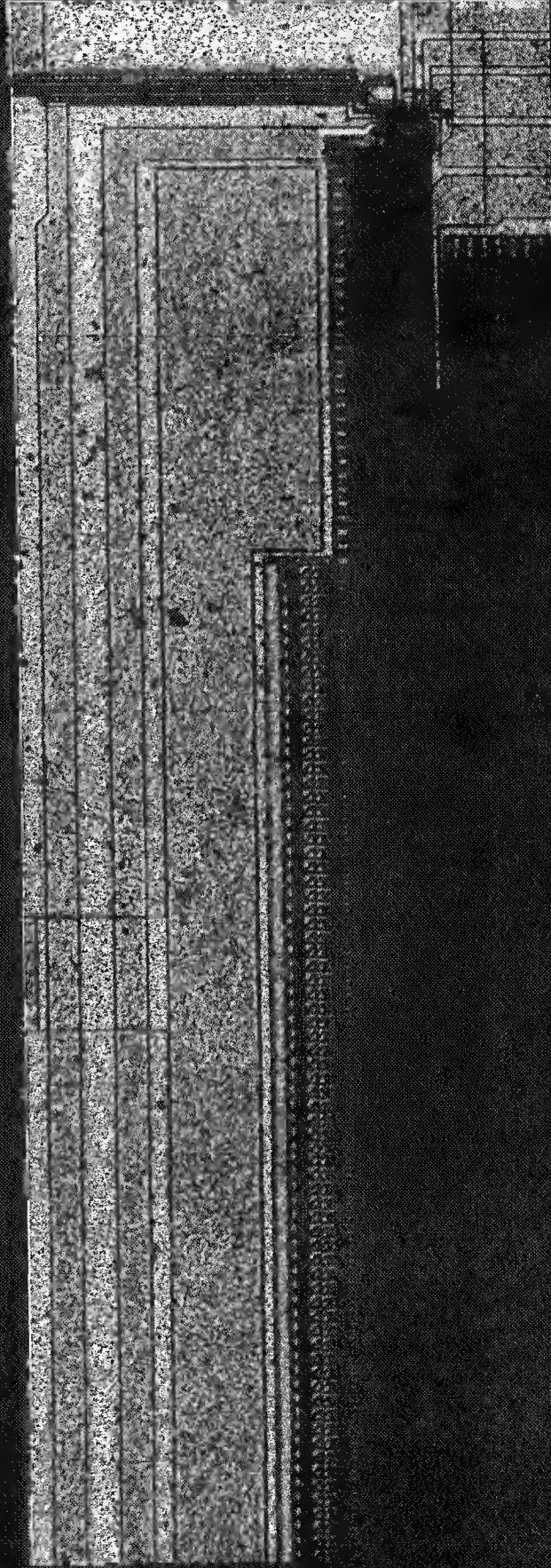
- Scan plane increased to avoid ceramic package
- Resolution decreases
- Corner selected for GMR zoom



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GMR Set-up and Current Map

- Probe contacts CCD surface
- 99 kHz frequency
- 2.0 mA current flow



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High-resolution GMR Scan

- Defect resolved to charge amplifier region with sub-micron resolution



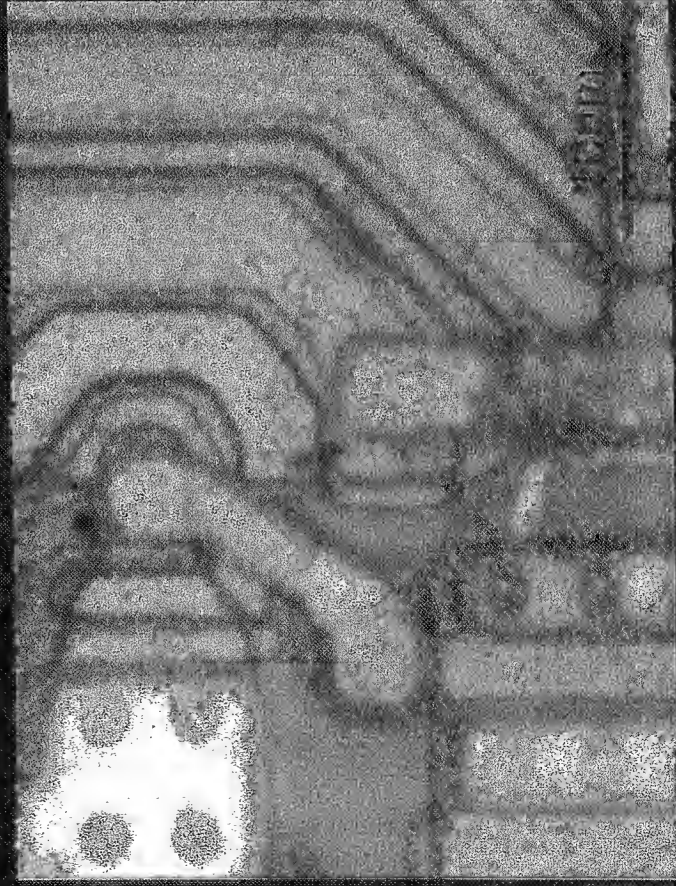
Thermal Imaging Microscopy

- Parallel polish CCD SN06
- InSb detector used
- Current of 5 mA and 10 mA
- No hot spot detected
- Defect possibly under M1 metallization

Deprocessing of CCD

- Light shield removed by parallel polishing
- Optical inspection find anomalies

SN09



SN06

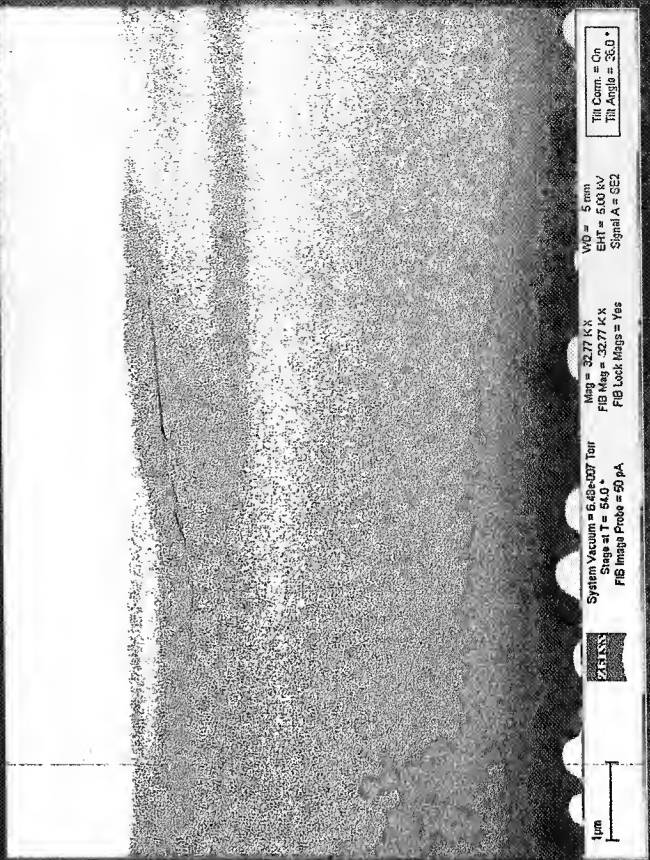
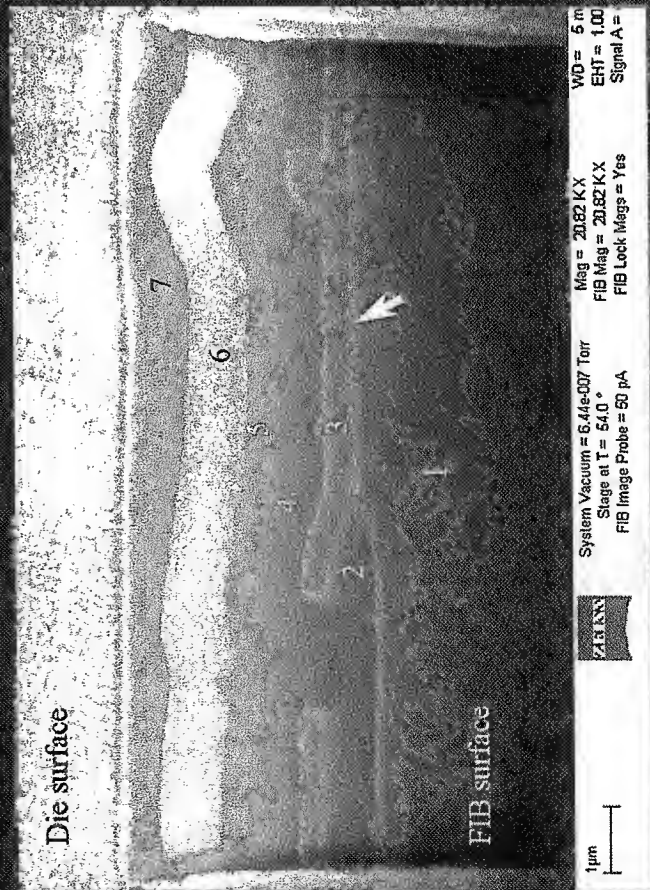


Cross-section at Anomaly

- SN06 FIB cross section
- Evidence of cracking, bridging

Undamaged corner

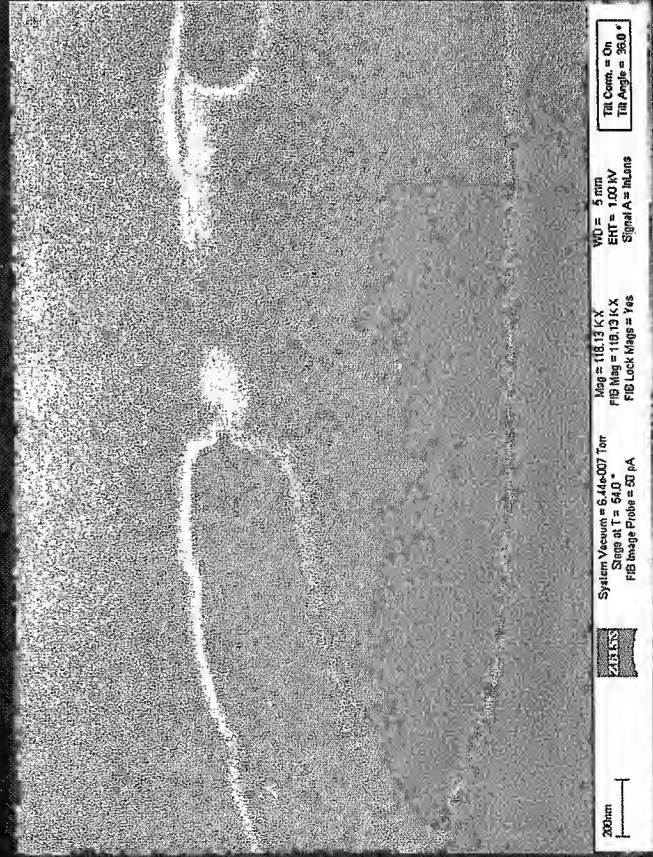
SWA/LA1 short L1



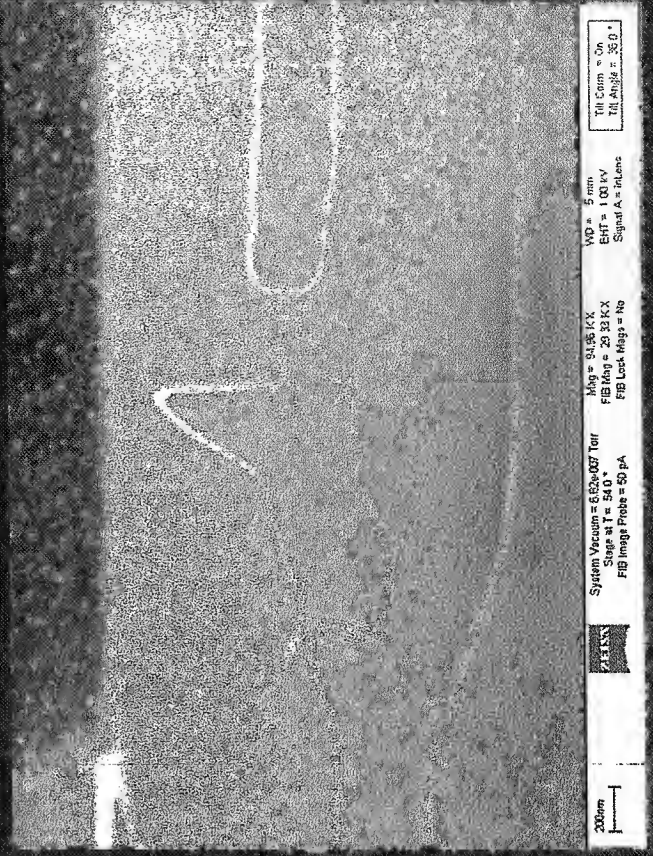
Cross-section at Anomaly

- SN06 FIB cross section
- Evidence of cracking, bridging

SWA/LA1 short L2

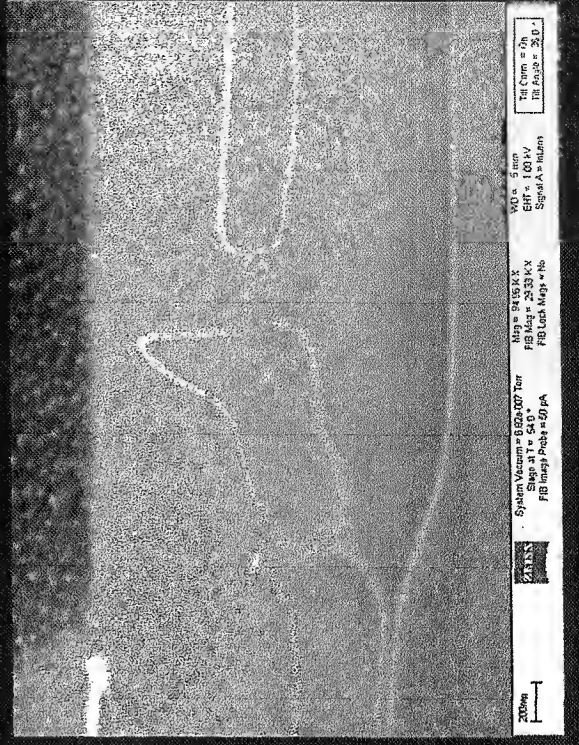
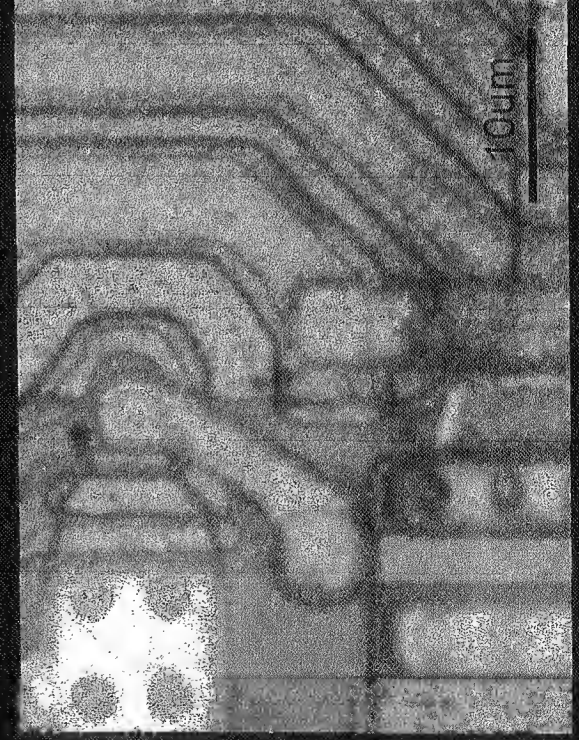


SWA/LA1 short L3



Summary Images

- ESD or line transient
- ..with possible secondary damage caused by IR testing



200um

SEI
Sputter Vacuum = 5.00E-07 Torr
Stage 1 T = 54.0 °C
FIB Image Probe = 50 pA
FIB Lock Magn = No
Map = 54.15 kV
FIB Mag = 25.33 kX
FIB Lock Magn = No
WD = 5 mm
GHT = 1.00 kV
Signal A = Intensity
The Camera = On
The Focus = 23.1